

MCEN 5151 Team First: Alcohol Suspended in Oil Floating at a Density Barrier

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ABSTRACT

Immiscible fluids of different densities rest on top of water.

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INTRODUCTION

The image in Figure 1 was produced for MCEN 5151 and the first team project. The team consisted of myself and classmates Sami Algoosi and Alessandro Sanchez. When planning for the project we discussed imaging the thin film effect, density columns, and fluid mixing streak- or streamlines. We each settled on different phenomena, but all used common household products such as dish soap and canola oil. Pictured in Figure 1 is a transient suspension of aguardiente (a distilled Colombian liquor, dyed green) bubbles in canola oil, all resting without mixing on a layer of water (dyed pink).

The image I produced was something of a "happy accident", from the phenomenon to the colors used. Sami had procured tattoo ink, dye particles in a water based solution. He had advised me to color the water pink and aguardiente green to contrast other fluid elements that were not so easily dyed. After the mostly transparent canola oil had settled, I went to pour in the aguardiente, expecting the liquor to settle atop the canola oil. Instead it sank into the oil without mixing, forming bubbles that sank to the boundary between the oil and water. In the time it took to ready the camera and the light, some of the aguardiente bubbles had popped (seen on the right) and comprised an interstitial layer between the oil and water. We can see something approximating sediment deposit in the distribution of the liquor.

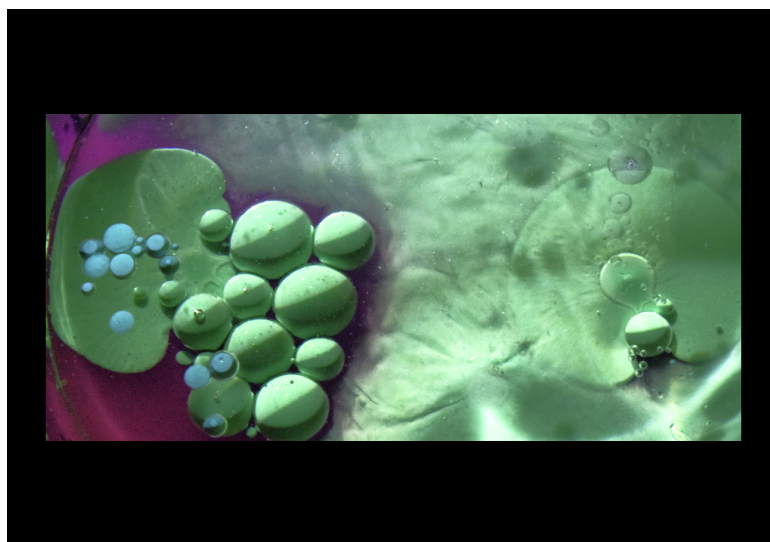


Figure 1. Finished image. Water has been dyed pink and aguardiente has been dyed green. The aguardiente bubbles are suspended in canola oil that sits atop water in a simple density column.

Fluids @ 20C	Canonical Density ($kg \cdot m^{-3}$)	Canonical Viscosity ($Ns \cdot m^{-2}$)
Water	992	1.001
Canola (Rapeseed) Oil	900	0.118
Alcohol (Ethanol, pure)	790	$118 \cdot 10^{-6}$
Aguardiente (30% ABV, estimated)	931	N/A

Table 1. Relevant properties for fluids pictured. Canola oil values are from *Properties of Food Processing* (Fellows). Aguardiente density approximated assuming the labeled 30% alcohol-by-volume.

FLOW PHYSICS

0.1 Density

Simple density is potentially the least interesting fluid effect visualized, but it deserves to be mentioned. Canonical densities and viscosities at 20 degrees Celsius are presented in Table 1. One can see why I had expected (perhaps hoped?) that aguardiente would float on canola oil due to the relative density of pure ethanol. A quick approximation of the density of aguardiente, assuming 30% alcohol by volume, reveals why it sank so quickly through canola oil, but resisted mixing with water.

0.2 Emulsions and Surface Tension

Despite using the phrasing "bubbles", my imaged system more closely resembles two immiscible phases (Sato and Sumita). Some insights into the oil-water interface behavior were gleaned from the oil industry (Tangparitkul et al.; Jiang et al.), but the dynamics investigated are typically inverted. That is, oil-droplets in water, sometimes with an additional gas phase. Direct comparisons and estimations of dynamics have been complicated, but we repeatedly encounter the Bond number and occasionally the see the Morton number.

The Bond number is a dimensionless number that encodes the ratio of gravitational to surface tension forces and is as follows:

$$Bo = \frac{\Delta\rho g L^2}{\gamma} \quad (1)$$

$\Delta\rho$ is the difference in density between the fluid phases, g is the Gravitational Constant, L is a characteristic length scale, and γ is the surface tension in $N \cdot m^{-1}$. For the Bond number of oil and aguardiente, we use the results of (Sato and Sumita) to approximate γ as $0.023 N \cdot m^{-1}$, find $\Delta\rho = 931 - 790 = 141 kg \cdot m^{-3}$, and length scales of $L = 1cm = 0.01m$. Thus we arrive at:

$$Bo = \frac{(141 kg \cdot m^{-3})(9.8 m^3 kg^{-1} s^{-2})(0.01m)^{-2}}{0.023 N \cdot m^{-1}} \approx 6 \quad (2)$$

It can be thought of as "Mass Component divided by Surface Tension Component" and relates gravitational and exterior fluid pressures to self-stabilization by surface tension. Large Bond numbers indicate that gravity dominates over surface tensions, either "popping" a bubble over the surface it sits on, or dragging the upper phase through the surface of another, forming a bubble. Despite small length scales, we see both the formation of bubbles as aguardiente sinks through canola oil the form bubbles, and then eventually pop after settling near the water layer. This seems to indicate that the oil and aguardiente exist in the unstable bubble regime described by (Park et al.).

The Morton number relates viscosity drag and surface tension of a bubble moving through a stagnant fluid, characterizing bubble speed and helping to approximate shape.

$$Mo = \frac{g \mu_c^4 \Delta\rho}{\rho_c^2 \sigma^3} \quad (3)$$

Here μ_c is the viscosity of the host fluid, ρ_c denotes density of the host fluid, and σ is the surface tension at the boundary. $\Delta\rho$ and g retain their meaning. Values of μ_c and ρ_c for canola oil are from Table 1, all else are the same values as used in the Bond number above. Thus:

$$Mo = \frac{(9.8 m^3 kg^{-1} s^{-2})(118 \cdot 10^{-6} Ns \cdot m^{-2})^4 (141 kg \cdot m^{-3})}{(790 kg \cdot m^{-3})^2 (0.023 N \cdot m^{-1})^3} \approx 3.53 \cdot 10^{-14} \quad (4)$$

For circular bubbles like we see in Figure 1, bubble velocity is primarily influenced by viscous forces, so a large Morton number would correspond with a slow-moving bubble (Pfister and Hager). With small Morton numbers, we expect rapid movement of bubbles, which makes sense considering the low viscosity of canola oil.

VISUALIZATION TECHNIQUES AND PHOTOGRAPHIC SPECIFICATIONS

Brightly colored tattoo dye was used to color water and aguardiente to be visible against each other and in canola oil. A flash light of approximately 280 Lumens was held directly against the side of the glass that was used for the density column and was manipulated by Alessandro Sanchez under direction. Some specular reflection can be seen in the bottom-right corner, opposite from where Alessandro was standing. The light was held at approximately the level of where canola oil and water met, such that the aguardiente bubbles were lit from the top left of the image.

The image was recorded on a Nikon D3300 with an AF-S Nikkor 18-55mm lens. Shutter speed was set to $\frac{1}{100}$ s with an ISO of 12800 and an f-stop of $\frac{f}{32.0}$. The camera lens was approximately 10cm from the lip of the glass holding the density column, and a field of view of 40% was heavily cropped. In addition to cropping, the image was minimally edited to increase contrast between the green and purple dyes. There was also a slight masking to remove some air bubbles from the top of the canola oil.

The image reveals an interesting interplay between density and immiscibility. Aguardiente has a density slightly less than that of water, but substantially greater than the canola oil, with which it is immiscible. Because the pictured phenomenon was largely an accident, I cannot say what intent was fulfilled. I am very pleased with the outcome, but with more intentionality would like to film the process of aguardiente drops forming and popping.



Figure 2. Unedited photo of aguardiente, canola oil, and water. Frank Herbert's Children of Dune in bottom right corner.

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